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Original Article

MULTI RESPONSE OBJECTIVE OPTIMIZATION OF FRICTION STIR WELDING PARAMETERS OF DISSIMILAR METALS OF AA 6061 ALUMINUMAND IS319 BRASS JOINING THROUGH TAGUCHI'S METHOD

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ABSTRACT

Dissimilar metals welding can be used where, combination of properties light weight and high strength was interested. Aluminium and Copper and its alloys are light metals have special properties, such as high electrical and thermal conductivities with excellent corrosion resistance. They can be used with combination in aerospace and automobiles industries. To join these dissimilar metals, a solid state friction welding is preferred over a conventional fusion welding, because of their typical metallurgical properties. In this present work, friction stir welding was performed to join two dissimilar Metals of AA6061Aluminum and IS319 Brass. A statistical method design of experiments through Taguchi approach was applied. The welding process parameters such as tool rotational speed, tool feed rate and tool pin geometry are optimized by considering the response parameter such as welding strength (UTS) and ductility (% of elongation). A grey relation grade is carried out with ANOVA to evaluate the significant contribution of process parameters. Optimal condition of parameters for sound welding was identified through this approach.

KEYWORDS: Friction Stir Welding, Dissimilar Metals, Multi Objective, Taguchi Method & ANOVA

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INTRODUCTION

Now days, with increase in demand for light weight materials for aerospace and automobiles applications, a continuous research is going on to find new combination of materials and advanced manufacturing techniques. A solid friction stir welding is the best process to join two dissimilar metal pieces as butt joint with minimum heat effect zone. In the process, welding tool consists of cylindrical shank with shoulder and pin rotates in prescribed speed and plunged into the work pieces butt line. Heat is generated, because of friction above recrystallization temperature and below the melting point. The tool moves longitudinally along the interface, thus weld form with minimum heat affected zone. The depth of tool pin was just below the thickness of the work piece, and diameter was one-third of shank diameter. The solid state Friction stir welding can be used to join similar or dissimilar metals either ferrous or non-ferrous alloys. In this welding, it is possible to control the properties of structural metals. The common welding defects and distortion that occurs in conventional fusion welding are minimized with this solid state welding.

The theory of Friction Stir Welding (FSW) and the weld strength required for structure, and its detailed researches are studied [1]. VIJAYAN [2] reported the optimization of process parameters for aluminum alloy using gray relational analysis and also given multiple objective optimization to get optimum response characteristics. The effect of FSW parameters such as spindle rotational speed, work table traverse speed, and stirrer geometry on ultimate tensile strength (UTS) and hardness of welded joints studied [3]. The optimal welding parameters and properties were identified by using desirability approach [4]. Finding the most effective parameters of friction stir welding process as well as realizing their influence on joint properties have been major topics for researchers [5−8]

Investigation done on the multi-objective optimization of the turning process of steel cylindrical bars to get minimum tool wear, surface roughness and roundness combination through Taguchi method, analysis of variance (ANOVA) and utility values were used with process parameters in turning [9]. The importance of each response is obtained by using intuition and multi objective convert, equivalent to single response with utility concept and ANOVA to get effective process parameters for WEDM [10].

The objective of this work is to join theAA6061Aluminum and IS319 Brass plates using friction stir welding and to study the process parameter. To join two plates, aluminum alloy with brass different tool profiles circular, triangular and square and different process parameters tool rotational speeds, tool feed rate are taken for experimentation. An orthogonal array L_9 is selected for design of experiments through Taguchi Method. A grey relation analysis with analysis of variance (ANOVA) was applied to get the optimal welding to yield good response ultimate tensile strength (UTS), ductility (% of elongation).

Figure.1: Conventional Milling Machine with Work Piece and Tool

EXPERIMENTATION

AA6061Aluminum and IS319 Brass plates of 150 mm x 75mm x 3 mm were supplied; its composition and strengths were given in table 1& 2. A conventional vertical 3 axis milling machine of maximum speed of 3000 rpm and 10 HP was used for friction stir processing. An orthogonal array L_9 was selected for experimentation, by considering 3 levels and 3 factors. The surface of the two sample plates were cleaned before welding and clamped firmly on the work table, keeping the butting line longitudinally along the table movement. The tool rotates at certain speed, plunged down in to the sample, so that, the pin may insert in already predrilled hole. The axial force of 7 tons was applied on welding tool. The work table moves longitudinally such that, sample pieces butting line pass through rotation tool. Here, the work table movement with certain feed rate is considered as tool feed rate. Totally, 9experiments were carried out with different tools in combination of factor and levels.

Table.1: Composition and strength of AA6061

Elements	Mg	Mn	Fe	Si	Cr	Cu	Al	UTS	% Elongation
AA 6061 Aluminum	1.2	0.13	0.34	0.57	0.35	0.23	Bal	283 MPa	13

Table.2: Composition and Strength of IS319 Brass

Elements	Cu	Pb	Fe	Zn	Impurities	UTS	% Elongation
IS319 Brass	61	2.4	0.35	35	0.5	390 MPa	9

Figure.2: Schematic Representation of Line Diagrams of FSW Tools

Tool Design

Three tools are designed by varying the tool pin geometry as shown in figure.2. The configuration of the design of Tool pin profiles is Circular, Triangular and Square and the D/d ratios of three are shown on table.3. High carbon high chromium was selected as a tool material, because of it s high strength, high temperature resistance. Tool having length 140mm, Shank diameter of 18mm and Tool pin depth is2.8 mm. The tool pin diameter is 6mm are prepared

Table.3: Levels and Factors

Factors→ / Levels↓	Tool rotational speed (rpm)	Tool feed rate (mm/min)	Tool geometry - (Dyn. Vol / Stat. Vol.)
1	710	32	Circular - 1
2	900	40	Square - 1.6
3	1120	56	Triangular - 2.4

Number of trails made by three levels of tool rotational speeds (710, 900, 1120 rpm), worktable translational or tool feed rate (32, 40, 56 mm/min) and tool pin geometry (circular, square and triangular), as per Taguchi design of experiments. The depth of pin is 2.8 mm for all tool providing flat surfaces to shoulder. The square and triangular pins were made in such way that the static volume was equal to that of the circular pin diameter. The pin geometry has been leveled according to the numerical values obtained from the ratio of tool pin dynamic volume to the static volume. The combinations of factors and level detailed design of experiments were given in Table 3. An orthogonal array L_9Taguchi design of experiments was applied to reduce the number of experiments and for each combination of parameters three sets of weld samples were conducted.

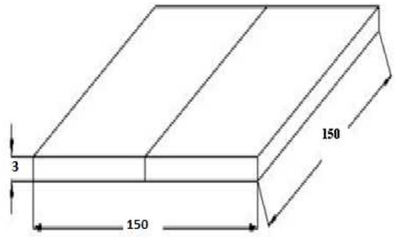

Figure.3: Welded joint piece of AA 6061 and IS319 Brass.

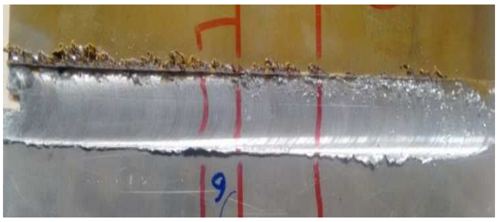

Figure.4: Schematic Diagram of the Butt Weld Position

Evaluation of Mechanical Properties

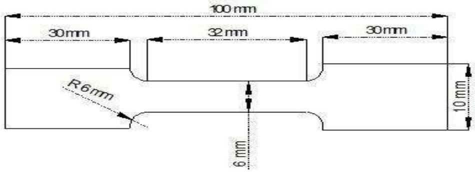

Figure.5.a): Specimens dimensions **b) tensile test Specimen**

The specimen for tensile test was prepared according to ASTM E8standards. Tensile test specimens were prepared by wire cut machine from each welded samples. The tensile strength for all weld specimens was recorded with Universal testing machine.

Multi-objective optimization with grey based approach

A grey relation analysis has been used to find optimal combination of parameters for good weld strength and ductility values. According to this approach all experimental result shown in Table.4 were normalized in the range from zero to one. The tensile strength (UTS) and % elongations values for 'the-larger-the-better' performance characteristic have been normalized as follows:

$$x_i^*(k) = \frac{x_i(k) - min x_i(k)}{max\ x_i(k) - min\ x_i(k)}$$

Where, k = 1 for UTS or 2 for % Elongation and *i* = 1 to 9 experiment numbers

Table.4: Input and Output Values after Experiments

Expt. No	Tool Rotation speed (rpm)	Feed Rate (mm/min)	Tool Geometry (Dyn. Vol. / Static Vol.)	UTS (MPa)	% Elongation
1	710	32	1	104.92	2.68
2	710	40	1.6	117.13	2.49
3	710	56	2.4	113.06	2.66

Table 4: Contd.,					
4	900	32	1.6	134.55	3.14
5	900	40	2.4	129.69	3.48
6	900	56	1	132.15	3.76
7	1120	32	2.4	120.97	3.02
8	1120	40	1	107.63	2.38
9	1120	56	1.6	124.86	2.52

After calculating normalized values, the grey relation coefficients were calculated as

$$\xi_i(k) = \frac{\Delta min + \xi\ \Delta max}{\Delta oi(k) + \xi \Delta max}$$

Where, $\Delta oi\ (k) = |x_0^*(k) - x_i^*(k)|$ is the difference of the absolute values x_{oi}^* (k) and x_i^* (k), ξ∈[0, 1] is distinguishing coefficient and ξ value 0.5 taken

$\Delta_{min} = min_{\forall j \in i}|x_0^*(k) - x_i^*(k)|$ is the smallest value for Δ_{oi}

$\Delta_{max} = max_{\forall j \in i}|x_0^*(k) - x_i^*(k)|$ is the largest value for Δ_{oi}

After calculating the normalized, grey relation coefficients and the grey relation grades are given in Table.5 were evaluated as:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$$

Where, 'γ_i' is the grey relation grade and 'n' is the no. of response parameters. The greater value of grey relation grade is taken for optimum process parameters.

Table.5: Normalized Value of Response and Grey Relation Grades

Expt. No	Normalized value of response		Grey Relation Coefficient		Grey Relation grade $\gamma_i = \frac{1}{2}\{\xi_i(1) + \xi_i(2)\}$	Rank
	UTS	% Elongation	UTS{ξ_i (1)}	% Elng{ξ_i (2)}		
1	0.0000	0.2173	0.3333	0.3898	0.3615	8
2	0.4120	0.0797	0.4595	0.3520	0.4058	6
3	0.2747	0.2028	0.4080	0.3854	0.3968	7
4	1.0000	0.5507	1.0000	0.5267	0.7634	2
5	0.8359	0.7971	0.7528	0.7113	0.7321	3
6	0.9190	1.0000	0.8605	1.0000	0.9303	1
7	0.5416	0.4637	0.5217	0.4824	0.5021	4
8	0.0914	0.0000	0.3549	0.3333	0.3441	9
9	0.6729	0.1014	0.6045	0.3575	0.4810	5

Optimal level of factors

For each experiment, grey relation grade average was calculated. Higher the grey relation grade indicates quality of response. According to higher value of grey relation grade, optimum level of each factor was evaluated. The average grey relation grades for optimal level of factors were shown in Table 6. The optimum parameters of tool rotation speed

(rpm), tool feed rate (mm/min) and tool geometry (Dyn. Vol./Static Vol.), according to grey relation grade was A2B3C1.

Table.6: Average Grey Relation Grade

Factors	Level-1	Level-2	Level-3	Maximum – Minimum.
A	0.3880	0.8086*	0.4424	0.4206
B	0.5423	0.4940	0.6027 *	0.1087
C	0.5453*	0.5501	0.5437	0.0952

Analysis of Variance

The greater Fisher value of ANOVA shown Table.7 indicates higher significant factor that influences response characteristics. In this analysis, tool rotational speed was identified most influenced factor, and followed by tool pin geometry. Worktable translation or tool feed rate was found as moderate factor. It has been identified through ANOVA analyses that, the welding parameters significantly affect the response characteristics identified.

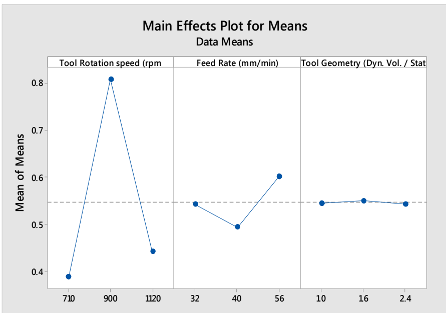

Figure.6: Mean effects plots for mean of GRG

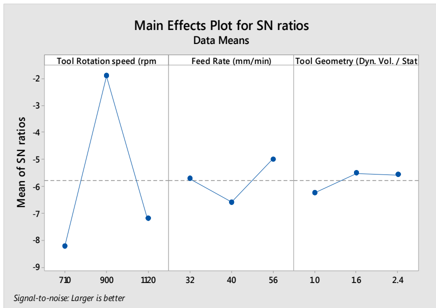

Figure.7: Mean Effects plots for S/N ratio of GRG

Table.7: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Tool Rotation speed (rpm	2	0.313934	0.156967	15.20	0.062
Feed Rate (mm/min)	2	0.017796	0.008898	0.86	0.537
Tool Geometry (Dyn. Vol. / Stat. Vol.	2	0.000066	0.000033	0.00	0.997
Error	2	0.020657	0.010329		
Total	**8**	**0.352454**			

Confirmation for Optimal Condition

The optimum level setting was identified as A3B2C1. Hence, the conformation grey relation grade calculated by

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{n}(\hat{\gamma}_i - \gamma_m)$$

Where, $\hat{\gamma}$issum of mean grey relation grade

The conformation grey relation grade is 0.8421,

The optimum factor of experiment exists in the designed experiments, hence no need to run the confirmation test. The grey relation grade at the optimum condition is 0.9303 and the obtained grey relation grade is 0.8421.

CONCLUSIONS

A butt joining of dissimilar IS319 Brass and AA 6061 aluminum alloy was successfully welded using FSW solid state welding technique. The samples were characterized by mechanical properties ultimate tensile strength, and ductility. The following conclusions were arrived from the present study.

- The optimal operating condition was 900rpm of tool rotational speed to join aluminum alloy AA6061and IS319 Brass plates, through FSW.
- From the experimental results, the better performance was identified at circular tool pin geometry, followed by other tool pin profiles.
- In combinations with rotation speed at 900rpm, axial force 7 kN, work table translation or tool feed rate at 32mm/min gives good response.

There is scope to achieve the best response parameters, by taking four factors in DOE with hexagon tool geometry.

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